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SCIENCE AND EXPLORATION OF A JUPITER TROJAN ASTEROID IN THE SOLAR POWER SAIL MISSION. T. Okada[1,2], T. Iwata[1], J. Matsumoto[1], J.-P. Bibring[3], S. Ulamec[4], R. Jaumann[4], R. Nakamura[5], H. Yano[1], Y. Kebukawa[6], J. Aoki[7], Y. Kawai[7], K. Terada[7], M. Toyoda[7], M. Ito[8], K. Yabuta[9], H. Yurimoto[1,10], Y. Saito[1], S. Yokota[1], C. Okamoto[11], S. Matsuura[12], K. Tsumura[13], D. Yonetoku[14], T. Mihara[15], A. Matsuoka[1], R. Nomura[1], T. Hirai[1], N. Grand[16], H. Cottin[16], L. Thirkell[17], C. Briois[17], T. Saiki[1], H. Kato[1], O. Mori[1], J. Kawaguchi[1], [1]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Japan, [2]University of Tokyo, Japan, [3]Institut d'Astrophysique Spatiale (IAS), Orsay, France, [4]German Aerospace Center (DLR), Germany, [5]National Institute of Advanced Industrial Science and Technology (AIST), Japan, [6]Yokohama National University, Japan, [7]Osaka University, Japan, [8]Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan, [9]Hiroshima University, Japan, [10]Hokkaido University, Japan, [11]Kobe University, Japan,[11]Kwansei Gakuin University, Japan, [12]Tohoku University, Japan, [13]Kanazawa University, Japan, [14]RIKEN, Japan, [15]LISA, Univ-Paris-XII, France, [16]CNRS, Orleans, France, Email: okada@planeta.sci.isas.jaxa.jp.

Introduction: Jupiter Trojan asteroids are located around the Sun-Jupiter Lagrange points (L4 or L5), and most of them are classified as D- or P-type, considered as volatile rich materials with rocks, water ices, and organics. However, the origin and evolution, composition and physical conditions of these bodies still remain unknown. Jupiter Trojans are the missing links of materials that originates from inner and outer solar system, and they are also intermediate size to undergo aqueous and thermal alteration between primitive smaller and evolved larger bodies. They are the key targets to understand the evolution process and the chemical radial distribution in the solar system.

An engineering mission to a Jupiter Trojan asteroid is being studied in Japan using a hybrid propulsion system of a large area solar-power sail (SPS) and a sophisticated ion engine [1]. After arriving there, the asteroid will be investigated for scientific purpose and for landing site selection by remote sensing. A lander will be deployed to land on the asteroid surface and conduct *in situ* observations.

A Jupiter Trojan multi-flyby mission (LUCY) [2] has been selected as the next Discovery class mission, which aims at understanding the variation and diversity of Jupiter Trojans, contrary to the SPS mission which will rendezvous and land on the asteroid and conduct in-depth measurements. The SPS mission is jointly studied between engineers and scientists both from Japan and Europe [3]. We will present here the key scientific objectives and the strawman payloads for the SPS mission.

SPS Mission Concept: The SPS mission is one of the candidates of the next medium class space science mission in Japan, and its Phase-A1 study is just begun under organization by the Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA). This mission is primarily proposed as an engineering demonstration based on technologies including the space yacht using a large-area (47m x 47m size) thin-film solar panel inherited from the IKAROS mission (the world first interplanetary space yacht) and the improved ion engine system inherited from Hayabusa mission (the world first sample return from asteroid). The large-area solar panel produces electric power enough to activate the ion engine even in the Jupiter orbit. The hybrid propulsion enables us to visit and explore the outer solar system without using a radioisotope thermoelectric generator (RTG).

The spacecraft of the SPS mission consists of a spin-stabilized main orbiter which rotates at 0.1 rpm and a 3-axis controlled lander to be deployed from the main orbiter. Its total wet mass is ca. 1300 kg, which is able to be launched directly to deep space by the H-2A launch vehicle. The lander is constrained to design within the wet mass of 100 kg, its body size within φ650 x 400 mm, and the equipment with extensionable landing legs and sampling devices. Mission payloads should be within 20 kg in total, including not only the science payloads, sampling system, electronics, as well as the sample container and transfer system in case of optional sample return [1]. The lander must work on the asteroid more than 20 hours with a primary battery of 600 WHr.

SPS Mission Design: The SPS will be launched late in 2020s, thrusted with the ion engine system, and change its trajectory using the Earth and Jupiter swing-bys in 5 to 6 years. It will finally rendezvous the target asteroid of Jupiter Trojans in 5 to 6 years, taking 11 years or more in total. During the first half period of the cruise phase, the spacecraft will travel from the Earth to Jupiter, and scientific observations will be conducted through the pathway to measure the radial distribution of our solar system. The second half period of the cruise phase from Jupiter to a Trojan asteroid, the spacecraft will cruise outside of the main asteroid belt, where the observations can be done much less influenced by the solar system dusts.

After arriving at the target asteroid, 20 to 30 km in diameter, the spacecraft will stay at the Home Position, several hundreds km sunward (or earthward) from the asteroid. The asteroid will be characterized and investigated in detail both for scientific purpose and for the landing site selection. The landing site will be determined from scientific and safety viewpoints. Then the spacecraft will descend nearer to the asteroid surface (1 km altitude), deploy a lander, and then ascend to a stable altitude of 250 km (TBD). The lander will descend to the asteroid surface using automatic optical navigation. The lander will be powered by the primary battery of total 600 WHr, and accomplish its mission on the asteroid for 20 hours. The data obtained in the lander will be transferred to the main orbiter at 1 Mbps and expected to send the data of 500 MB in total. Sample return from a Trojan asteroid is also under study as an option. The lander will ascend after collecting the samples, rendezvous and dock on the main orbiter. The samples will be sent and contained into the reentry capsule. It will take ca. 30 years in total if the sample-return is conducted.

Science in the SPS Mission: In the SPS mission, science experiments also have significant importance and will be carried out multi-disciplinarilly during the cruise phase, asteroid rendezvous phase by remote sensing, *in situ* observations on asteroid, and optional analysis of returned samples.

Cruise Science: In the SPS mission, it takes more than 10 years to arrive at the target asteroid and the science experiments should be considered by use of special environments to be undergone during the cruise phase. In the first half period from the Earth to Jupiter, the radial distribution in the solar system of solar wind magnetic field, solar system dusts, and their interrelations will be studied. A fluxgate magnetometer with three search coils (MGF) mounted at the end of solar power sail, and a large-area dust monitor (ALDN2) on the solar power sail are now considered for the purpose. Both instruments have the heritages in the IKAROS and other missions. The dust in the equatorial region of the solar system known as the source of zodiacal light will be observed with an infrared imaging spectrometer (EXZIT), which will be based on the sounding rocket experiment (Cyber).

After moving outside of the asteroid main belt and the second half period from Jupiter to a Trojan asteroid, infrared astronomy under the dust free conditions (low background conditions) will be highlighted to perform using EXZIT, in order to observe the first generation stars in initial universe. Gamma ray bursts are the key targets to understand the phenomena that occurred in the initial universe, and the very long baseline gamma ray interferometry between the Earth and a gamma ray detector (GAP2) on the spacecraft will be carried out to search for gamma ray bursts. GAP2 has heritage in the IKAROS mission.

Science of Trojan Asteroids: A classical (static) model of solar system evolution suggests that they formed around the Jupiter region and survive until now as the outer end members of asteroids. On the other hand, a new (dynamical) model such as Nice model [4] indicates that they formed at the far end of the solar system and then transferred inward due to dynamical migration of giant planets. Therefore, the physical, mineralogical, and isotopic studies of surface materials and volatile compounds could solve their origin and evolution processes, as well as the solar system formation. To achieve these goals, the surface experiments with the lander as well as characterization of the whole surface from the mothership are required.

The asteroid will be characterized and investigated such as high-resolved surface global mapping by using an optical telescopic imager, as well as the surface mineralogy and the degree of hydration mapping by a near-infrared and also a thermal-infrared hyperspectral imager (1 to 4 μm, 7 to 14 μm), with spatial resolution of higher than several tens of meters.

Just after landing on the asteroid surface, geological, mineralogical, and geophysical observations will be conducted to characterize the landing site in detail, using a panoramic camera, an infrared hyperspectral imager (covering 1 to 4 μm), a magnetometer, and a thermal radiometer. The surface material composition will be classified with a Raman spectroscopy. A close-up imager will monitor the surface condition. Materials from surface and subsurface layers will be collected and inserted into a carousel. The surface sampler is the impact sampling type, inherited from Hayabusa and Hayabusa2 missions. The subsurface sampler (down to 1000 mm) is newly developed using pneumatic drill.

Samples by each shot will be viewed by visible and infrared microscope (covering 1 to 4 μm) with a spatial resolution of 10 to 20 μm per pixel to be identified and classified. Those samples will be heated by step-wise heating for high resolution mass spectrometry (HRMS). Mass resolution $m/\Delta m > 30{,}000$ is required to investigate isotopic ratios of D/H, $^{15}N/^{14}N$, and $^{18}O/^{16}O$, as well as molecules from organic matters (M = 30 to 1000). For the HRMS, the MULTUM type in Japan and the Cosmorbitrap type in France are considered as the candidates. Development of both methods is on-going to improve their performances.

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